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Indian Standard

SPECIFICATION FOR POLYCRYSTALLINE SEMI-CONDUCTOR RECTIFIER STACKS

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INDIAN STANDARDS INSTITUTION
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

Gr 6 *December* **1963**

Indian Standard

SPECIFICATION FOR POLYCRYSTALLINE SEMI-CONDUCTOR RECTIFIER STACKS

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SPECIFICATION FOR POLYCRYSTALLINE SEMI-CONDUCTOR RECTIFIER STACKS

0. FOREWORD

0.1 This Indian Standard was adopted by the Indian Standards Institution on 27 November 1963, after the draft finalized by the Power Converters Sectional Committee had been approved by the Electrotechnical Division Council.

0.2 Rectifier equipments making use of polycrystalline semi-conductor rectifier units are being widely used due to the fact that for all moderate sizes the semi-conductor rectifier units have been found more convenient and economical than the vacuum tube or mercury vapour rectifier. The manufacture of such rectifier units is yet to be fully developed in this country; therefore, it has been felt that an Indian Standard on the subject will serve as a proper instrument for guiding the production.

0.3 This specification relates to the polycrystalline rectifier units, such as those of selenium and copper oxide. It is intended to cover the general requirements and tests applicable to the completed rectifier equipment in a separate standard which is under preparation.

0.4 While preparing this standard, assistance has been derived from the following:

IEC PUBLICATION No. 119-1960 RECOMMENDATIONS FOR POLYCRYSTALLINE SEMI-CONDUCTORS RECTIFIER STACKS AND EQUIPMENT. International Electrotechnical Commission.

B. S. 2709 : 1956 SEMI-CONDUCTOR RECTIFIER (METAL RECTIFIERS). British Standards Institution.

0.5 Wherever a reference to any Indian Standard appears in this specification, it shall be taken as a reference to the latest version of the standard.

0.6 For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test, shall be rounded off in accordance with IS : 2-1960 Rules for Rounding Off Numerical Values (*Revised*). The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

0.7 This standard is intended chiefly to cover the technical provisions relating to polycrystalline semi-conductor rectifier stacks, and it does not include all the necessary provisions of a contract.

1. SCOPE

1.1 This standard applies to polycrystalline semi-conductor rectifier stacks and stack assembly used for supplying dc power from ac sources at frequencies up to 2 000 c/s.

1.2 This standard does not apply to telecommunication rectifiers other than those for power supplied to such apparatus, nor to rectifiers used as auxiliaries to measuring instruments. Further, it does not include the main transformer or other associated transformers and apparatus, nor does it apply to rectifiers based on mono-crystalline semi-conductor materials.

2. TERMINOLOGY

2.0 For the purpose of this standard, the following definitions shall apply.

2.1 Rectifier — A device for converting an alternating or oscillating current into a unidirectional current, either by inversion or suppression of alternate half-waves.

2.2 Semi-conductor Rectifier — A rectifier using the properties of a semi-conductor as the basis of operation.

2.3 Rectifier Cell — A basic rectifier, consisting of a combination of semi-conductors or a semi-conductor and a metal or metals in contact with one another, which presents an asymmetrical conductance according to the polarity of the voltage applied to it (*see* Fig. 1).

2.4 Rectifier Stack (Unit) — A single structure of one or more rectifier cells with its (their) associated mounting(s), cooling attachment(s), if any, (for example a blower or fan) and connections whether electrical or mechanical (*see* Fig. 2).

2.5 Rectifier Stack Assembly — An electrically and mechanically combined structure of one or more rectifier stacks, complete with all its connections together with the means for cooling, if any, (for example a blower or fan) in its own mechanical structure (*see* Fig. 3).

2.6 Rectifier Equipment — An operative assembly comprising one or more rectifier stacks, together with transformers and other auxiliaries, if any, for conversion of ac into dc (*see* Fig. 4).

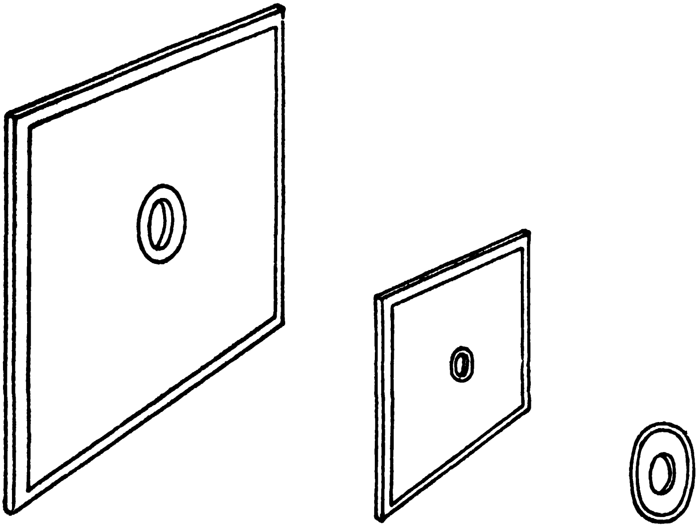


FIG. 1 RECTIFIER CELL

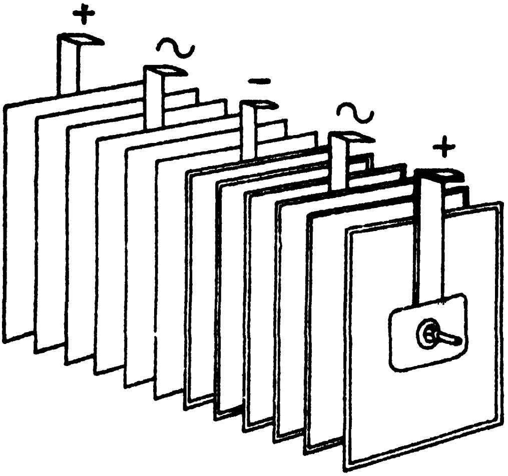


FIG. 2 RECTIFIER STACK (UNIT)

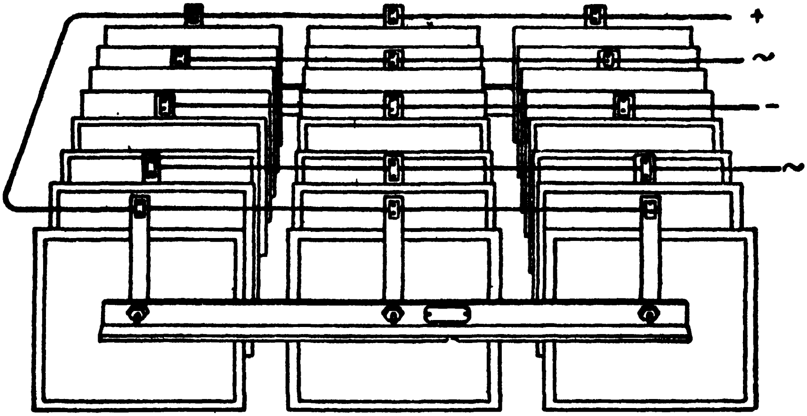


FIG. 3 RECTIFIER STACK ASSEMBLY

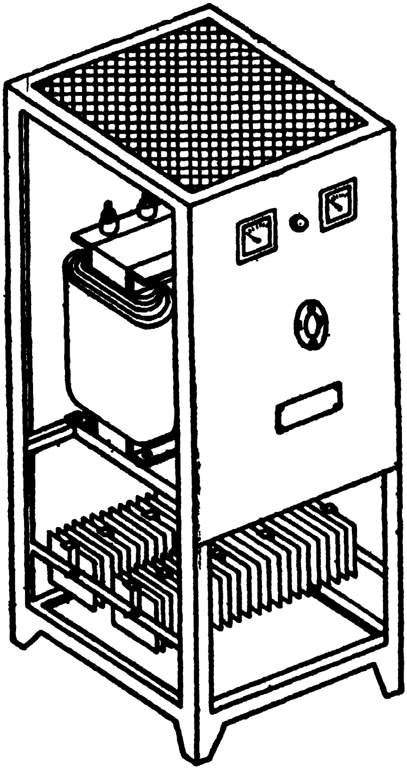


FIG. 4 RECTIFIER EQUIPMENT

2.7 Rectifying Element — A circuit element bounded by one positive and one negative terminal, and having the characteristic of conducting effectively only in one direction (*see* Fig. 5).

NOTE — In practice, a rectifying element may be derived from one cell, or a number of cells interconnected in either series, parallel or series-parallel arrangement. Therefore, the corresponding component may either be a part or the whole of a stack, a stack containing a single cell, or a stack assembly.

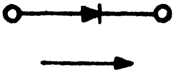


FIG. 5 RECTIFYING ELEMENT

2.8 Rectifier Connection — A connection of one or more rectifying elements for conversion of ac into dc (*see* Fig. 6).

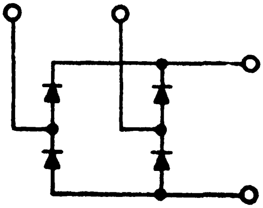


FIG. 6 RECTIFIER CONNECTION

2.9 Arm of a Rectifier Connection — One rectifying element of a rectifier connection (*see* Fig. 7).

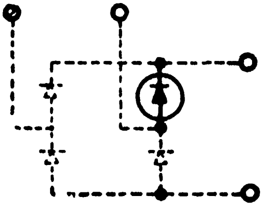


FIG. 7 ARM OF A RECTIFIER CONNECTION

2.10 Forward Direction — The direction of a rectifying element which has the higher conductance.

2.11 Reverse Direction — The direction of a rectifying element which has the lower conductance.

2.12 Average Forward Current — The average value of the current in the forward direction of a rectifying element excluding the reverse current and measured over a full cycle.

2.13 Average Reverse Current — The average value of the current in the reverse direction of a rectifying element excluding the forward current and measured over a full cycle.

2.14 Forward Voltage Drop — The voltage drop which results from the flow of forward current through a rectifying element.

2.14.1 *Average Forward Voltage Drop* — The average value of the forward voltage drop of a rectifying element excluding the reverse voltage and measured over a full cycle.

2.15 Reverse Voltage — The voltage which is applied to a rectifying element in the reverse direction.

2.15.1 *Working Reverse Voltage* — The peak value of the reverse rated voltage (excluding transient over voltage) divided by $\sqrt{2}$.

2.16 Forward Power Loss — The power loss resulting from the flow of current in the forward direction.

2.17 Reverse Power Loss — The power loss resulting from the flow of current in the reverse direction.

2.18 DC Blocking — The action of rectifying element which essentially prevents the flow of direct current in the reverse direction in a dc circuit.

2.19 DC Blocking Voltage — A substantially smooth dc voltage applied in the reverse direction of a rectifying element.

2.20 Barrier Layer — The layer within a semi-conductor rectifier cell which has the asymmetric conductance.

2.21 Forming — Electrical and/or thermal treatment of semi-conductor cells or stacks for the purpose of increasing the effectiveness of the barrier layer. (An increase of the effectiveness of the barrier layer may also take place in service or during storage.)

2.22 Loss of Forming — A partial loss in the effectiveness of the barrier layer.

2.23 Re-forming — The operation of restoring by an electric treatment, the effectiveness of the barrier layer after loss of forming.

2.24 Ageing — A gradual persisting change, except failure, which takes place in the forward or reverse resistance characteristic, when the rectifier is in use.

2.25 Shelf Ageing — A gradual persisting change, except failure, which takes place in the forward or reverse resistance characteristic, when the rectifier is not in use.

2.26 Positive Creep Effect — A gradual increase in the reverse current which may occur when a substantially smooth dc blocking voltage (*see* **2.19**) is applied to a semi-conductor rectifying element.

2.27 Stack Temperature — The stack temperature of a semi-conductor rectifier stack measured at the hottest accessible point.

2.28 Conversion Efficiency — The ratio of the product of the average value of dc voltage and direct current to the input active power on the ac side. (Expressed in this way the maximum efficiency for the single-phase bridge connections on resistance load with sinusoidal supply is 0·81.)

2.29 Ratings — A statement of the performance of rectifier under the rated conditions assigned by the manufacturer.

2.30 Rated Service Conditions — The service condition for which the ratings apply.

2.30.1 *Service Conditions* — All external factors (ambient temperature, air humidity, type of load, etc) which may have influence on the performance of the rectifier.

2.31 Rated Service Time — The period of time for which the rectifier is rated to give the rated value of the voltage between the dc terminals at the rated current.

2.32 Ambient Temperature — The temperature of the ambient air immediately below the rectifier stacks.

2.33 Type Tests — Tests carried out to prove conformity with the requirements of this specification. These are intended to prove the general qualities and design of a given type of rectifier stack.

2.34 Routine Tests — Tests carried out on each rectifier stack to check requirements likely to vary during production.

3. RATINGS

3.1 Semi-conductor rectifiers shall be rated in terms of ac rms input voltage of approximately sinusoidal form and of mean dc output voltage and current.

3.1.1 *Basic Circuit* — The basic rating shall be for operation on a single-phase bridge circuit with a purely resistive load with unaided and unimpeded convection cooling in clean air.

The ratings of a rectifier stack may be calculated from the rating of the reference rectifier stack in the basic circuit. A manufacturer may, therefore, give the ratings of a series of stacks comprising one type of cells by referring to the rating of a reference stack, composed of the same type of cells.

3.1.2 *Ambient Temperature* — The basic rating shall apply to 40°C ambient temperature.

3.1.2.1 Other ambient temperatures of 45°C, 55°C and 70°C are also recognized and the manufacturer shall, on the request of the purchaser, provide a rating for the required temperature(s).

3.1.3 *Basis of Rating* — The basis of rating is such that during the first 2 000 hours under the conditions specified in **3.1.1** and with the rating appropriate to the ambient temperature (*see* **3.1.2**), the output voltage does not fall below 90 percent of the rated voltage.

3.2 Rated Direct Current — The rated dc output current shall be given as the average value of the direct current at the dc terminals of the reference rectifier stack for continuous service 24 hours a day.

3.3 Rated DC Voltage — The rated dc voltage shall be given as the average value of the voltage between the dc terminals which can be obtained during the entire rated service time (*see* **7.1**) without the rated ac voltage being exceeded.

3.3.1 Due to the ageing in the forward direction, the rated dc voltage shall be given with a margin for the expected increase in voltage drop. In order to obtain the rated dc voltage, therefore, a new stack shall be run at a recommended ac voltage lower than the rated ac voltage.

3.4 Rated AC Voltage — The rated ac voltage shall be given as the rms value of the maximum continuously permissible line-to-line ac voltage to be applied to the rectifier stack.

3.4.1 The manufacturer shall also state the value of the commencing ac voltage below the rated ac voltage at which a new stack gives rated dc voltage (*see* **3.3.1**). Rated ac voltage shall not exceed the commencing ac voltage by more than 15 percent.

3.5 Duty Factor — The duty factors, intermittence (*see* **3.5.1**) or utilization factors (*see* **3.5.2**), shall be stated. The manufacturer shall, if requested, advise the purchaser about the rating for required duty factors.

Where no duty factors are stated, it shall be taken to mean continuous service 24 hours a day.

3.5.1 *Intermittence Factor* — This factor shall be stated as the ratio between load time and total time between the beginning of two sequential load periods for intermittent loads, where the load period is too short to give stationary temperature conditions.

3.5.2 *Utilization Factor* — This factor shall be stated as the ratio between the load time and the total time for non-continuous load where each load period is long enough to give practically stationary temperature conditions.

3.6 **Types of Load** — For the purposes of rating, the type of rectifier load should be specified, that is resistive load, inductive load, capacitive load, battery load, machine load or combination of loads. If not otherwise specified, the load shall be taken to be resistive.

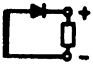
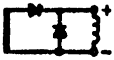
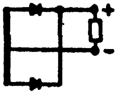
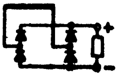
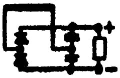
3.7 The rating of rectifiers may be increased by assisted cooling; on the other hand, if rectifiers are used under conditions of restricted cooling, the rating will be reduced.

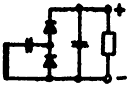
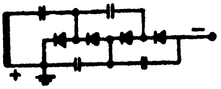
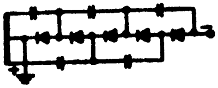
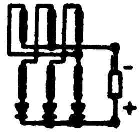
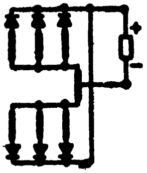
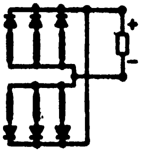
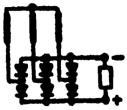
3.8 Under conditions of use not covered by the standard, the manufacturer, in consultation with purchaser, will specify an appropriate rating.

3.9 For some useful information on the basis of ratings *see* Appendix A.

4. METHODS OF CONNECTION

4.1 Rectifier stacks may either be completed in one of the forms given in the following list, or more than one stack may be used to complete such a form of circuit connections:

Item	Connection	Name	Pulse Number
1		Half-wave connection	1
2		Back-wave connection	1
3		Centre-tap connection	2
4		Single-phase bridge connection	2
5		Voltage-doubler bridge connection	2

Item	Connection	Name	Pulse Number
6		Two-step voltage-doubler connection	1
7		One-pulse voltage multiplier	1
8		Two-pulse voltage multiplier	2
9		Three-phase star (shown with zig-zag transformer as an example)	3
10		Six-phase star	6
11		Double three-phase star (with interphase transformer)	6
12		Three-phase bridge	6

5. MARKING

5.1 Each rectifier stack shall be clearly and indelibly marked with the following information:

a) The manufacturer's name and/or trade-mark,
b) Date of manufacture (may be given by quarter),
c) Country of manufacture,
d) The following symbols or colours for the terminal markings:

Terminal	*Symbol*	*Colour*
AC	~	Yellow
DC positive	+	Red
DC negative	—	Blue

5.2 The code designation as given in Appendix B shall also be marked on the stacks.

5.3 Where suitable, the forward direction of stacks forming rectifying elements shall be indicated by an arrow (for example, on rod-shaped stacks).

5.4 Rectifier stacks may also be marked with the ISI Certification Mark.

NOTE — The use of the ISI Certification Mark is governed by the provisions of the Indian Standards Institution (Certification Marks) Act and the Rules and Regulations made thereunder. The ISI Mark on products covered by an Indian Standard conveys the assurance that they have been produced to comply with the requirements of that standard under a well-defined system of inspection, testing and quality control which is devised and supervised by ISI and operated by the producer. ISI marked products are also continuously checked by ISI for conformity to that standard as a further safeguard. Details of conditions under which a licence for the use of the ISI Certification Mark may be granted to manufacturers or processors, may be obtained from the Indian Standards Institution.

6. VOLTAGE-CURRENT CHARACTERISTIC CURVES, DATA AND POWER LOSSES

6.1 Voltage-Current Characteristics and Data

6.1.1 All data given for the stacks shall refer to the ambient temperature for which the new stacks are rated.

6.1.2 The currents and voltages in the circuit to which the characteristic curves and data refer shall be stated.

6.1.3 Characteristic curves shall preferably be given for rectifying elements or single cells of a rectifier.

6.1.4 It shall be clearly stated whether a characteristic curve refers to stationary dc values, average values during rectifier operation or instantaneous values during rectifier operation.

NOTE — In most cases, the characteristics of a rectifying element valid for stationary dc do not apply at rectifier operation because of the dynamic physical phenomena in the cells.

6.1.5 Unless otherwise specified, the characteristic curves for rectifier operation shall be taken to apply for single-phase bridge operation with resistance load (*see also* **3.1.1**).

6.1.6 Drawing of characteristic curves in either of the two alternatives given in Fig. 8 is recommended.

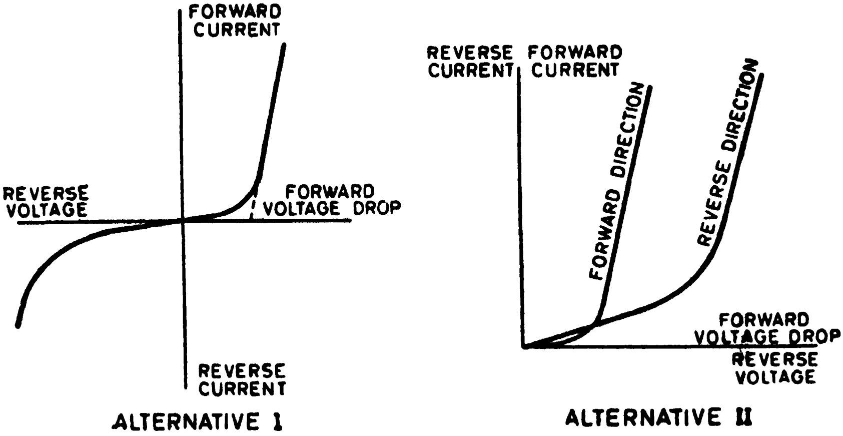


FIG. 8 CHARACTERISTIC CURVES

6.2 Power Losses

6.2.1 The power losses given shall apply to the new stack and specified service conditions.

6.2.2 It shall be stated whether the losses given apply to rectifier cell, rectifier stack or other configuration.

6.2.3 When giving data for stacks being built from certain types of cells, the losses per cell shall preferably be given (*see also* Appendix C).

7. PERFORMANCE REQUIREMENTS

7.1 Service Time

7.1.1 During the service time, which applies for rated service (comprising a given duty factor) and includes the off time, the ac voltage has to be increased for maintaining the rated dc voltage on account of the steady increase in the forward voltage drop. But at the end of the rated time, the ac voltage necessary shall be the rated ac voltage and shall not be increased further. As the forward voltage drop is steadily increasing, the rated dc voltage can no longer be obtained (*see* Fig. 9).

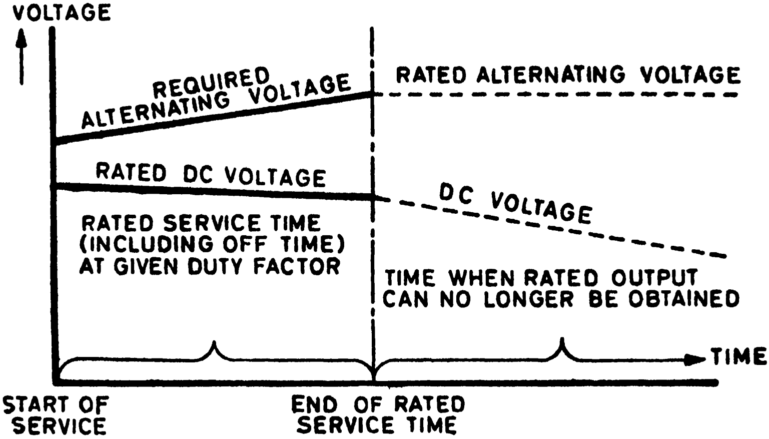

VOLTAGE
REQUIRED ALTERNATING VOLTAGE
RATED ALTERNATING VOLTAGE
RATED DC VOLTAGE
DC VOLTAGE
RATED SERVICE TIME (INCLUDING OFF TIME) AT GIVEN DUTY FACTOR
TIME WHEN RATED OUTPUT CAN NO LONGER BE OBTAINED
TIME
START OF SERVICE
END OF RATED SERVICE TIME

Fig. 9 Service Time

7.1.2 The storage period before the rectifier is put into operation is not included in the rated service time.

7.2 Reverse Voltage

7.2.1 A stack shall withstand, without damage or permanent change of its characteristics, operation at 110 percent of the rated ac voltage and the maximum permissible ac reverse voltage respectively at no load for a period of 5 minutes each.

7.2.2 A rectifier stack, when required by application and so specified by the purchaser, shall continuously withstand its rated dc voltage applied to the dc terminals when the alternating current is interrupted.

7.2.3 When a stack, having been out of service or having been in service at low voltage, cannot be directly connected to its rated ac voltage and rated reverse voltage respectively, without damage or permanent change in its characteristics, the manufacturer shall state, if required, the procedure for re-forming the stack.

7.3 Insulation

7.3.1 The insulation between the cells and the spindle as well as different insulated parts of the same stack shall be tested.

7.3.2 The insulation shall withstand, unless otherwise specified, an ac rms voltage having a frequency between 40 and 60 c/s and given by the formula,

$$2 \times \frac{U_p}{\sqrt{2}} + 1\,000\ V$$

with a minimum of 2 000 V for a period of one minute. U_p is the peak value of the highest voltage which occurs between two terminals of the stack at rated service.

7.3.3 Where $\frac{U_p}{\sqrt{2}}$ is not higher than 90 V, insulation may be tested at a lower voltage than given in **7.3.2**, which shall be clearly stated by the manufacturer.

8. TESTS

8.1 Type tests for approval and routine tests during manufacture shall be applied as detailed below:

Type Test	*Routine Test*
Inspection (**8.2**)	Inspection (**8.2**)
Forward Voltage Drop (**8.3**)	Forward Voltage Drop (**8.3**)
Reverse Leakage (**8.4**)	Reverse Leakage (**8.4**)
High Voltage (**8.5**)	High Voltage (**8.5**)
Output Voltage (**8.6**)	
Conversion Efficiency (**8.7**)	
Load (**8.8**)	
Shelf Life (**8.9**)	

8.1.1 The type tests shall be made by a recognized testing authority which may be the manufacturer itself.

8.2 Inspection

8.2.1 The rectifiers shall be subjected to a general inspection for the quality of workmanship and finish.

8.3 Forward Voltage Drop Test

8.3.1 The average voltage drop measured at the temperature of 27 ± 5°C and between adjacent pairs of terminals shall not exceed 1·5 volts per series connected cell when the normal rated dc output current of the section under test is caused to flow in the conducting direction of the rectifier (*see also* Appendix C).

8.4 Reverse Leakage Test

8.4.1 The rectifier stack or stacks shall be connected as a single-phase bridge, the output terminals of the bridge being unconnected. The rated ac input voltage shall be applied to the input terminals of the bridge and input current measured by a moving coil rectifier instrument at a temperature of 27 ± 5°C. The mean value of this current shall not exceed 7 percent of the rated dc load current for the bridge after an interval of 30 seconds from the application of the voltage (*see also* Appendix C).

8.5 High Voltage Test

8.5.1 All the terminals in the same circuit shall be connected together and the test voltage in accordance with 7.3 shall be applied between the terminals and the spindle and between the different circuits, if there are more than one on the same spindle, for a period of one minute. There shall be no breakdown or other evident deterioration.

8.6 Output Voltage Test

8.6.1 For this test, the rectifier unit in association, if necessary, with others of the same type shall be connected into a single-phase bridge circuit and operated on resistance load at its rated current and input voltage. The input shall be obtained from a low impedance source of sinusoidal voltage.

8.6.2 The dc output voltage shall be measured and shall not be less than the manufacturer's rated figure.

8.6.3 Where it is also important that a maximum value shall not be exceeded, the purchaser shall draw the attention of the supplier to this fact at the time of enquiry and order.

8.7 Conversion Efficiency Test

8.7.1 Under the test conditions of **8.6**, the measurement of input voltage, input watts, mean output currents and mean output voltage shall be recorded and the conversion efficiency calculated (*see* **2.28**).

8.8 Load Test

8.8.1 At the commencement of the test the conditions shall be as in **8.6.1**. The rectifier shall be loaded in an ambient temperature of 40°C continuously for the rated service time. The load resistance shall be kept constant. The input voltage shall be started at a recommended lower value (*see* **3.3.1**). At the end of the service time, the rated ac input voltage shall not give less than the rated output dc voltage.

8.8.2 Where rectifiers have been specified for operation at other ambient temperatures (*see* **3.1.2.1**), this test shall be carried out at the appropriate ambient temperature and rating.

8.9 Shelf Life Test

8.9.1 The rectifier stack shall be stored for a period of six months under clean and dry condition and at all times in equilibrium with the atmospheric conditions of the room. At the end of this period, the rectifier stack shall be capable of meeting the requirements of **8.2** to **8.6** after re-forming, if necessary.

APPENDIX A

(*Clause* 3.9)

RATINGS OF RECTIFIER STACKS

A-1. BASIS OF RATING

A-1.1 The rectifier stacks are largely rated on thermal basis, that is ratings are chosen so that the corresponding internal heat losses will not result in excessive stack temperatures.

A-1.1.1 Internal heat losses in stacks consist of: (a) the forward loss due to the passage of load current through the forward resistance of the cells, and (b) the reverse loss due to the flow of reverse or leakage current through the reverse resistance of the cells.

A-1.1.2 Since the forward resistance decreases with increasing cell temperature, the forward loss also decreases with increasing temperature at any given load. Also since the reverse voltage remains substantially constant for a given load, the reverse loss increases with increasing temperature because of the decreasing reverse resistance.

A-1.1.3 The total internal heat loss in watts is the sum of the forward and reverse losses and may vary directly or inversely with the cell temperature or may remain substantially constant over a wide range of temperature depending upon the choice of voltage and current per cell.

A-1.1.4 In general, standard cell ratings will give a substantially constant value of internal heat loss over the normal range of indoor ambient temperatures. The shape of the loss curve is so matched to the heat dissipation curves of the various types of stack structures so that stable operation will result after the cells are fully aged or if the ambient temperature, for any reason, should occasionally exceed the specified value.

A-1.2 When a rectifier stack has more than one cell in series per element, it is only necessary to multiply the voltage rating for the specified circuit by the number of cells in series to get the total voltage rating of the stack. Likewise, when there is more than one cell in parallel per element, the current rating should be multiplied by the number of cells in parallel to get the total current rating of the stack.

APPENDIX B

(*Clause* 5.2)

CODE DESIGNATION OF STACKS

B-1. CODE DESIGNATION

B-1.1 The following different codes should be included in the code designation.

B-1.1.1 *Structure Code* — A code giving the structure of the stack with regard to connection and number of cells in series and parallel per arm.

B-1.1.2 *Rating Code* — A code giving ratings of the stack.

B-1.1.3 *Manufacturer's Code* — A code specified by the manufacturer to give such information which is not included in the structure code.

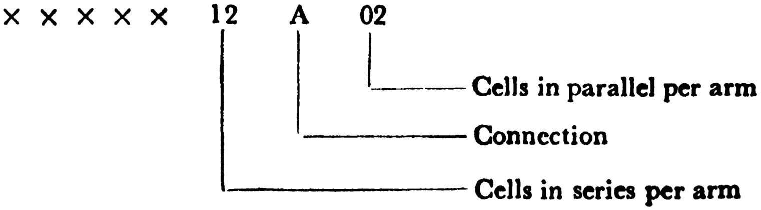
B-2. DESCRIPTION OF CODE

B-2.1 The code consists of letters and figures in 10 positions, in which the last five positions are the structure code according to this specification and the first five positions are the manufacturer's own code for other indications not given in the structure code, such as ratings, brackets, finish, etc.

× × × × ×	× × × × ×
Manufacturer's Code	Structure Code

B-2.2 The first two positions of the structure code should normally be figures indicating the number of cells in series per arm, including 0 for numbers below 10. The third position shall normally be a letter indicating the stack connection according to **B-2.3**. The fourth and fifth positions shall normally be figures indicating the number of cells in parallel. When one of these numbers needs 3 positions, the letter is moved one step to the right or left.

Example 1:

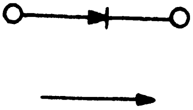
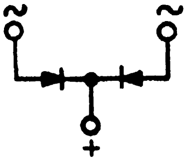
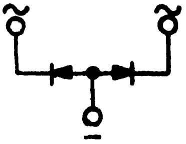
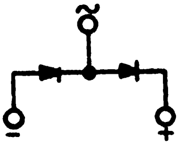
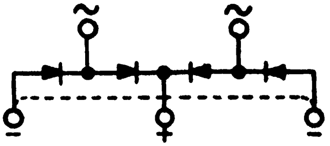
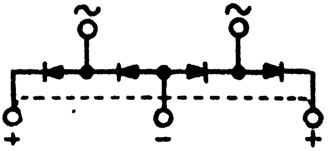


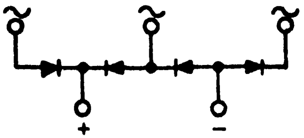
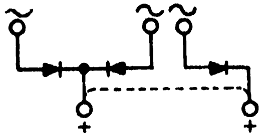
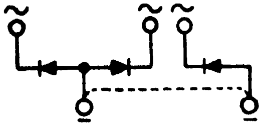
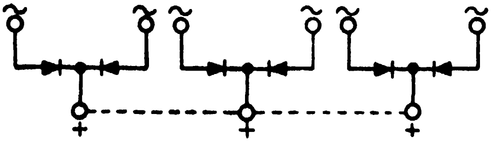
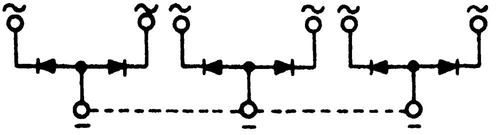
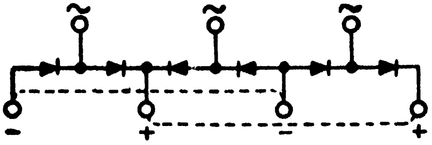
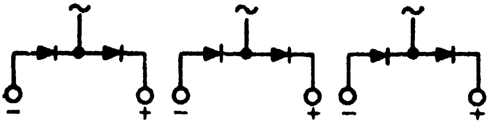
Example 2:

× × × × × 123 A 1

B-2.3 Code letters according to the following table shall be used for designating the stack connection.

NOTE — As these designations refer only to the structure of stacks, these connections may be used for several purposes. The connections *F* and *S* may be used with or without interphase transformer. More stacks may be combined to form another connection, for example two *D* stacks may be used to make a single-phase bridge.

Item	Connection	Name	Code Letter
1		Half-wave	A
2		Centre-tap, positive	C
3		Centre-tap, negative	N
4		Voltage doubler	D
5		Single-phase bridge, negative outer	B
6		Single-phase bridge, positive outer	P

ITEM	CONNECTION	NAME	CODE LETTER
7		Open bridge, single-phase	H
8		Three-phase star, common positive	E
9		Three-phase star, common negative	Y
10		Six-phase star, common positive	F
11		Six-phase star, common negative	S
12		Three-pulse bridge	G
13		Open bridge, three-phase	K

B-2.3.1 The manufacturer's code shall always end with a letter, as the next position is the first figure of the structure code.

APPENDIX C

(*Clauses* 6.2, 8.3 *and* 8.4)

TEST METHODS

C-0. GENERAL

C-0.1 Power losses, forward voltage drop and reverse current are preferably measured with the same arrangement. Unless otherwise specified, these measurements shall be carried out for rated dc voltage and direct current.

C-1. PROCEDURE

C-1.0 The simplest method is a short-circuit and open-circuit test, where the loss values are calculated from the measured values.

C-1.1 The rectifier is connected to the instruments in accordance with Fig. 10.

C-1.2 The short-circuit test gives the forward power losses and forward voltage drop. The open-circuit test gives the reverse power losses and reverse current.

C-1.3 As the waveshape of the forward current is different from that in actual service, the measured value of forward power losses has to be corrected according to the following formula:

$$P_1 = C_w P$$

where

P_1 = actual value of forward power losses,

P = measured value of forward power losses,

$$C_w = \frac{2nU_{th}.I_{d1}}{P}\left[1 - \left(\frac{I_{L1}}{I_L}\right)^2\right] + \left(\frac{I_{L1}}{I_L}\right)^2 .$$

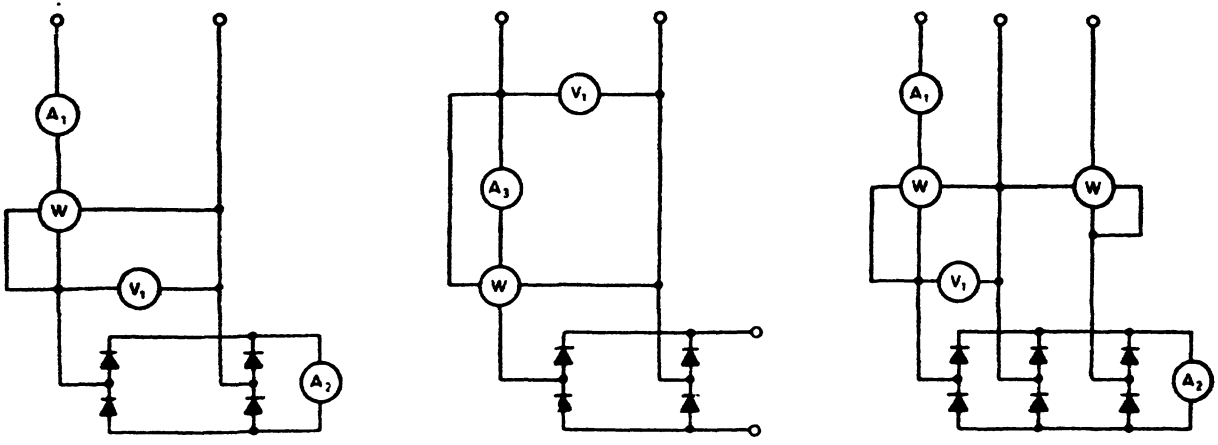
n = number of cells in series per arm,

U_{th} = threshold voltage of the cells (*see* below),

I_{d1} = rated direct current,

I_{L1} = rms value of alternating current at rated service, and

I_L = rms value of alternating current on the measuring connection.



SHORT CIRCUIT

OPEN CIRCUIT

SHORT CIRCUIT

A_1 = ac ammeter.
A_2 = Moving coil ammeter (low voltage drop).
A_3 = Moving coil ammeter with rectifier for measuring the average reverse current.
V_1 = ac voltmeter.
W = Electro-dynamic wattmeter.

NOTE — Ammeters, voltmeters and wattmeters used in this connection diagram shall be of an accuracy class not inferior to 1·5 [*see* IS : 1248-1968 Specification for direct acting electrical indicating instruments (*first revision*)].

FIG. 10 CONNECTION DIAGRAM

The threshold voltage U_{th} is the voltage which has to be overcome before any appreciable current flows in the forward direction. It only needs to be known with ± 20 percent accuracy for the calculation of the correction factor (*see also* Fig. 8):

C-1.4 The forward voltage drop is measured during the short-circuit test with the voltmeter V_1. As the voltmeter V_1 indicates the rms value, the average forward voltage drop is obtained by dividing the indicated voltage by 2·22 for both the single-phase and the three-phase bridge connections.

C-1.5 When desirable, the forward power losses in single-phase connection can be measured with sinusoidal current by connecting a resistor in series on the ac side of the connection shown in Fig. 10, left. The resistor shall absorb a voltage about 5 times the voltage drop of the stack. When such a resistor is used, the voltage measured by the voltmeter V_1 is no longer sinusoidal and the true average value can only be obtained by using an instrument indicating average value. The measured value of power loss is the correct value and does not need any correction as suggested in **C-1.3**.

C-1.6 The milliammeter A_3 indicates twice the average reverse current. As the waveshape can vary, a moving coil instrument with a rectifier shall be used to get the average value.

NOTE — In this measurement the capacitive current component is included. This component might influence the measured value considerably and is less significant than the ohmic component of the reverse current.

INTERNATIONAL SYSTEM OF UNITS (SI UNITS)

Base Units

Quantity	*Unit*	*Symbol*
Length	metre	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	kelvin	K
Luminous intensity	candela	cd
Amount of substance	mole	mol

Supplementary Units

Quantity	*Unit*	*Symbol*
Plane angle	radian	rad
Solid angle	steradian	sr

Derived Units

Quantity	*Unit*	*Symbol*	*Definition*
Force	newton	N	1 N = 1 kg.m/s^2
Energy	joule	J	1 J = 1 N.m
Power	watt	W	1 W = 1 J/s
Flux	weber	Wb	1 Wb = 1 V.s
Flux density	tesla	T	1 T = 1 Wb/m^2
Frequency	hertz	Hz	1 Hz = 1 c/s (s^{-1})
Electric conductance	siemens	S	1 S = 1 A/V
Electromotive force	volt	V	1 V = 1 W/A
Pressure, stress	pascal	Pa	1 Pa = 1 N/m^2

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Manak Bhavan, 9 Bahadur Shah Zafar Marg, New Delhi 110002

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